MURRAY BASIN
NRM CLUSTER

CLIMATE CHANGE IN AUSTRALIA
IMPACTS & ADAPTATION INFORMATION FOR AUSTRALIA'S NRM REGIONS

Impact of climate change on runoff and recharge in the Murray Basin

Synthesis of previous work

Russell Crosbie, Linda Broadhurst, and Veronica Doerr

Citation

Crosbie, R., Broadhurst, L. and Doerr, V. (2015) Impact of climate change on recharge and runoff in the Murray Basin: Synthesis of previous work. CSIRO, Australia.

Copyright

Disclaimer

An Australian Government Initiative

Contents

We recommend using this synthesis to inform 'Step 3: Assess the impacts of climate change on values' in The NRM Adaptation Planning Framework: six steps to transform NRM planning under global change (Ryan et al. 2016)

Executive Summary

This report provides a synthesis of previous studies into the impacts of climate change on runoff and recharge across the Murray Basin Natural Resource Management (NRM) Cluster region. This comprises multiple individual NRM regions spread across southern New South Wales, the Australian Capital Territory, northern Victoria and south-eastern South Australia.

The most recent studies into climate change impacts on runoff and recharge have been used. The runoff results were part of the South East Australian Climate Initiative (http://www.seaci.org/) which used 15 global climate models (GCMs) with two global warming (emissions) scenarios and were reported in Post et al. (2012). The recharge results were part of the Climate Change Impacts on Groundwater Resources Project (Barron et al., 2011) which used 16 GCMs and three global warming (emissions) scenarios and were reported in Crosbie et al. (2013).

For this report, these existing modelling results were analysed according to representative climate futures (Whetton et al., 2012) as an aid to effective communication. The most frequent climate futures amongst the suite of GCMs were for warmer temperatures and little change in rainfall, and slightly hotter temperatures and drier rainfall for both the runoff and recharge modelling. Across the Region these representative climate futures projected a decrease in both runoff and recharge as a median; however, the extreme outlier projections for both runoff and recharge can exceed ±50%.

As a result, there was considerable variation in model results both across NRM regions as well as within regions across different climate models. This suggests that planning within and across regions needs to be adaptive and responsive to changing conditions as the precise degree and even direction of change cannot be determined for certain.

Photo credit Willem van Aken

Photo credit Greg Rinder

1.1 Introduction

The Murray Basin NRM Cluster region covers some 500,000 km2 of New South Wales, Australian Capital Territory, Victoria and South Australia (Figure 1). It is extremely diverse and includes flat plains to high mountains, above- and below-ground water resources and a broad range of biodiversity. Many different types of agriculture also occur in this region.

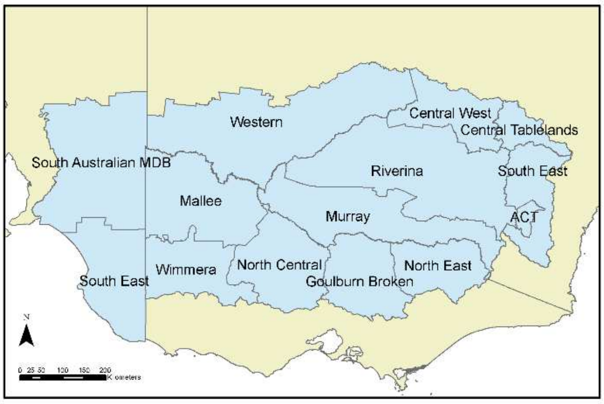

Figure 1. Map of the Murray Basin NRM Cluster region showing the original boundaries and individual NRM regions included.

During the preparation of this report, New South Wales (NSW) NRM group boundaries were restructured resulting in some of the NSW NRMs now being bisected by the cluster boundary. As data analysis and synthesis were already underway at the time of the NSW restructure, the original NRM boundaries were retained. This report provides a synthesis of previous studies of climate change impacts on runoff and groundwater recharge with the results presented as representative climate futures for each of the original NRM regions.

1.2 Previous studies

There has not yet been a thorough analysis of the impacts of climate change on runoff and recharge across the Murray Basin using CMIP5 global climate model (GCM) runs. Thus, a synthesis of our current understanding needs to be drawn from previous studies using CMIP3 runs. The details of these studies are as follows:

The first comprehensive assessment of the impact of climate change on the water resources of the Murray Basin was conducted as part of the Murray-Darling Basin Sustainable Yields Project (CSIRO, 2008). This project used 15 GCMs using daily scaling downscaling (Chiew et al., 2009) with three global warming scenarios (+0.7, +1.0 and +1.3°C) to produce 45 projections of future runoff (Chiew et al., 2008) and recharge (Crosbie et al., 2008). These were then simplified down to three scenarios (wet, median and dry) for further analysis. The GCM runs used were the CMIP3 runs (Meehl et al., 2007).

The methods used in the Sustainable Yields Projects were further refined and applied for the Murray Darling Basin Authority Basin Plan (Crosbie et al., 2010a; Crosbie et al., 2010b). This largely followed the same pattern as the Sustainable Yields Projects using the same GCMs, downscaling methods and global warming scenarios.

The most recent projections of runoff under a future climate were conducted as part of the South-East Australian Climate Initiative (SEACI) (CSIRO, 2012). This study (Post et al., 2012) used 15 GCMs with the A1B SERES scenario (Nakicenovic and Swart, 2000) archived by CMIP3 (Meehl et al., 2007) with the daily scaling downscaling method (Chiew et al., 2009) for a +1.0 and +2.0°C global warming scenarios which are ~2030 and ~2070 respectively using the SIMHYD model (Chiew et al., 2002). These projections were made at a spatial resolution of 0.05° (~5 km).

The most recent projections of recharge under a future climate were conducted as part of the Climate Change Impacts on Groundwater Resources Project (Barron et al., 2011). This study (Crosbie et al., 2013; Crosbie et al., 2010c) used 16 GCMs with the A2 SERES scenario (Nakicenovic and Swart, 2000) archived by CMIP3 (Meehl et al., 2007) with the daily scaling downscaling method (Chiew et al., 2009) for a +1.0, +1.7 and +2.4°C global warming scenarios (which can be thought of as ~2030, ~2050 and ~2070 respectively) using the WAVES model (Zhang and Dawes, 1998). These projections were made at a spatial resolution of 0.05° (~5 km).

For this synthesis report it is the work of Post et al. (2012) and Crosbie et al. (2013) that have been summarised. The reader is referred to the original documents for a thorough description of the modelling. A spatial representation of the change in runoff and recharge for each individual GCM and global warming scenario is shown in Appendix A .

1.3 Representative Climate Futures

Representative climate futures (Whetton et al., 2012) are a method of reducing the complexity associated with communicating the results of climate change impact studies. Representative climate futures are categorical descriptions of the results of climate models (see http://www.climatechangeinaustralia.gov.au/en/climate-projections/). This can reduce many hundreds of scenarios (emissions scenarios x GCMs x downscaling method x future period) to a manageable number of representative climate futures. For this project there are a total of 20 possible climate futures defined by a change in rainfall (from much drier to much wetter) and a change in temperature (from slightly warmer to much hotter).

Figure 2 shows the range of representative climate futures considered in this project along with the data available from the runoff and recharge studies. The way the scenarios were constructed for the previous hydrological modelling constrains the representative climate futures for which data is available. There is data available for the warmer (+0.5°C to +1.5°C) and slightly hotter (+1.5°C to +3.0°C) categories for both runoff and recharge. The original modelling studies did not consider <+0.5°C to be a feasible increase in temperature by 2030 and the >+3°C was not considered feasible before 2070. The change in rainfall aspect of the representative climate future comes from the GCMs. As the runoff and recharge used a different suite of GCMs, the data available is slightly different and ranges from much drier (< -15% rainfall) to wetter (+5 to +15%) for the runoff and from much drier to much wetter (> +15%) for the recharge.

The most frequent representative climate futures for the runoff modelling across the Murray Basin were warmer temperatures and little change in rainfall (Table 1) and slightly hotter temperatures and drier rainfall (Table 2). Note that individual NRM regions could be more likely to experience other representative climate futures, such as those that are slightly hotter and much drier. However, we worked with the futures with the most consensus across models for the Cluster region as a whole.

For recharge, the most frequent representative climate futures were warmer temperatures and little change in rainfall (Table 3) and slightly hotter temperatures and drier rainfall (Table 4). Similarly with the runoff modelling, not all regions are consistent throughout the Murray Basin.

Change in Rainfall	Change in Temperature: Slightly Warmer <+0.5°C	Warmer +0.5 to +1.5°C	Slightly Hotter +1.5 to +3.0°C	Much Hotter > +3.0°C
Much Drier < -15%	×,×	✓,×	✓,✓	×,×
Drier -15 to -5%	×,×	✓,✓	✓,✓	×,×
Little Change -5 to +5%	×,×	✓,✓	✓,✓	×,×
Wetter +5 to +15%	×,×	×,✓	✓,✓	×,×
Much Wetter > +15%	×,×	×,×	×,✓	×,×

Figure 2. Representative Climate Futures used in this project. The ticks and crosses represent where we have data from the runoff and recharge modelling respectively.

1.3.1 Runoff results

For the warmer climate with little change in rainfall, all regions have a median result of a reduction in runoff (Table 1) with the highest being a 2% reduction (Central West LLS) and the lowest being a 14% reduction (North Central CMA). As there are multiple GCMs that sit within this representative climate future there is a range of runoff projections with, the greatest range being between -15% and +14% from 8 GCMs (Mallee).

In other words, for the warmer climate with little change in rainfall, different models suggest different changes in runoff. The degree of variability among the model results varies across NRM regions in the Murray Basin Cluster with some models suggesting increases and some decreases.

For the warmer, drier representative climate future all GCMs for all regions project a decrease in runoff. The median results range from -12% (Western LLS) to -28% (ACT NRM).

There are no regions that have more than 1 GCM for the warmer, much drier climate future and there are no GCMs for either the warmer, wetter or warmer, much wetter climate futures.

Under the slightly hotter temperature category the drier rainfall is the most frequent and has a range of median runoff projections from -17% (Western LLS, Mallee CMA) to -32% (North Central CMA; Table 2.). As there are multiple GCMs there is considerable spread in the projections within this climate future with the greatest range in the SA MDB with projections from -45% to -9%.

There are also a significant number of projections in the slightly hotter, little change in rainfall climate future. The median projection for every region is a reduction in runoff ranging from -2% (Western LLS) to -18% (Wimmera CMA).

Some of the projections also fall into more extreme categories with slightly hotter, much drier category having a median of up to -53% (North Central CMA) and slightly hotter, wetter having a median of up to +52% (Western LLS).

1.3.2 Recharge results

The warmer climate with little change in rainfall is the most frequent climate future for the recharge projections in the warmer climate category. There is a spread between the regions with some indicating a median projection of an increase in recharge and some a decrease in recharge (Table 3.). The highest median is for +3% (Central Tablelands LLS, North Central CMA) and the lowest is -9% (Western LLS). As there are multiple GCMs there is a considerable spread around the median for each region with the greatest range being from -14% to +16% (ACT NRM).

For the warmer, drier climate future all GCMs for all regions suggest a decrease in recharge. The median projection ranges from -20% (ACT NRM) to -9% (Central West LLS).

There are a limited number of projections in the warmer, slightly wetter climate future with up to a

+17% change in recharge (Central Tablelands LLS, Central West LLS). There are no GCMs in the warmer, much drier or warmer, much wetter climate futures.

For the slightly hotter and drier climate future all regions have a median projection of a reduction in recharge (Table 4) ranging from -2% (Riverina LLS) to -19% (Western LLS). As there are many GCMs in this climate future there is a considerable spread in the projections with most regions spanning both an increase and decrease in recharge.

For the slightly hotter, little change in rainfall climate future most regions have a median of an increase in recharge, the range is from -8% (Western LLS) to +15% (Central Tablelands LLS).

There are also projections that fall into more extreme categories with slightly hotter, much drier category having a median of up to -45% (Western LLS) and slightly hotter, wetter having a median of up to +47% (ACT NRM).

Table 1. Climate futures for a warmer future climate showing the change in runoff for 15 GCMS. Derived from Post et al. (2012).

	Much Drier				Drier				Little Change				Wetter				Much Wetter			
Region	Median	Count	min	max	Median	Count	min	max	Median	Count	min	max	Median	Count	min	max	Median	Count	min	max
Central Tablelands	-46%	1	-46%	-46%	-27%	3	-30%	-14%	-7%	11	-13%	5%								
South East					-21%	6	-36%	-21%	-9%	9	-18%	-1%								
Western	-43%	1	-43%	-43%	-12%	7	-17%	-12%	-4%	7	-10%	11%								
Central West	-46%	1	-46%	-46%	-14%	7	-22%	-14%	-2%	7	-10%	8%								
Riverina	-38%	1	-38%	-38%	-14%	6	-23%	-14%	-4%	8	-14%	5%								
Murray	-30%	1	-30%	-30%	-14%	6	-20%	-14%	-3%	8	-13%	4%								
ACT					-28%	3	-40%	-28%	-9%	12	-16%	6%								
Goulburn Broken					-20%	7	-29%	-20%	-8%	8	-14%	-2%								
Mallee					-16%	7	-35%	-16%	-10%	8	-15%	14%								
North Central					-21%	8	-39%	-21%	-14%	7	-25%	-2%								
North East					-19%	7	-33%	-19%	-6%	8	-13%	4%								
South Australian MDB					-24%	6	-33%	-24%	-8%	9	-17%	0%								
Wimmera					-24%	6	-36%	-24%	-12%	9	-25%	-2%								

Table 2. Climate futures for a slightly hotter future climate showing the change in runoff for 15 GCMS. Derived from Post et al. (2012).

	Much Drier				Drier				Little Change				Wetter				Much Wetter			
Region	Median	Count	min	max	Median	Count	min	max	Median	Count	min	max	Median	Count	min	max	Median	Count	min	max
Central Tablelands	-52%	3	-72%	-46%	-21%	4	-24%	-12%	-8%	6	-21%	9%	11%	2	11%	12%				
South East	-53%	2	-59%	-46%	-25%	8	-42%	-15%	-9%	5	-17%	-2%								
Western	-24%	5	-66%	-1%	-17%	4	-22%	-14%	-2%	4	-5%	2%	52%	2	25%	78%				
Central West	-32%	4	-70%	-1%	-24%	3	-35%	-22%	-7%	6	-19%	2%	35%	2	18%	51%				
Riverina	-44%	2	-62%	-26%	-22%	7	-41%	-6%	-6%	4	-25%	1%	12%	2	11%	12%				
Murray	-40%	2	-52%	-27%	-21%	7	-36%	-5%	-5%	4	-23%	0%	8%	2	8%	8%				
ACT	-48%	3	-65%	-44%	-23%	5	-27%	-14%	-13%	5	-26%	11%	11%	2	11%	11%				
Goulburn Broken	-43%	2	-50%	-37%	-21%	7	-38%	-11%	-13%	6	-26%	-3%								
Mallee	-41%	4	-57%	-23%	-17%	6	-25%	3%	-4%	4	-19%	15%	38%	1	38%	38%				
North Central	-53%	2	-61%	-45%	-32%	10	-48%	-15%	-14%	3	-27%	-1%								
North East	-37%	3	-57%	-37%	-21%	6	-35%	-12%	-11%	5	-24%	-3%	10%	1	10%	10%				
South Australian MDB	-45%	3	-55%	-37%	-19%	6	-45%	-9%	-15%	5	-23%	2%	2%	1	2%	2%				
Wimmera	-49%	4	-57%	-34%	-31%	8	-42%	-16%	-18%	3	-21%	-1%								

Table 3. Climate futures for a warmer future climate showing the change in recharge for 16 GCMS. Derived from Crosbie, et al. (2013).

	Much Drier				Drier				Little Change				Wetter				Much Wetter			
Region	Median	Count	min	max	Median	Count	min	max	Median	Count	min	max	Median	Count	min	max	Median	Count	min	max
Central Tablelands					-13%	3	-14%	-10%	3%	11	-12%	9%	17%	2	17%	18%				
South East					-14%	6	-21%	-5%	-2%	10	-13%	5%								
Western					-23%	3	-34%	-18%	-9%	12	-17%	4%	9%	1	9%	9%				
Central West					-9%	4	-20%	-8%	1%	10	-5%	10%	17%	2	13%	21%				
Riverina					-14%	4	-20%	-10%	0%	12	-7%	12%								
Murray					-14%	4	-19%	-9%	-2%	12	-9%	8%								
ACT					-20%	2	-23%	-18%	-3%	14	-14%	16%								
Goulburn Broken					-16%	6	-23%	-9%	-4%	10	-10%	6%								
Mallee					-11%	6	-30%	-7%	-1%	10	-8%	9%								
North Central					-13%	9	-26%	-7%	3%	7	-6%	5%								
North East					-17%	4	-19%	-13%	-8%	12	-11%	6%								
South Australian MDB					-13%	7	-28%	-9%	-2%	9	-14%	4%								
Wimmera					-13%	9	-29%	-2%	0%	7	-13%	4%								

Table 4. Climate futures for a slightly hotter future climate showing the change in recharge for 16 GCMS. Derived from Crosbie, et al. (2013).

	Much Drier				Drier				Little Change				Wetter				Much Wetter			
Region	Median	Count	min	max	Median	Count	min	max	Median	Count	min	max	Median	Count	min	max	Median	Count	min	max
Central Tablelands	-17%	3	-21%	-10%	-8%	10	-19%	13%	15%	14	0%	26%	37%	5	35%	59%				
South East	-28%	5	-36%	-4%	-12%	15	-28%	1%	11%	12	1%	20%								
Western	-45%	3	-55%	-27%	-19%	9	-26%	7%	-8%	11	-12%	14%	19%	8	9%	32%	51%	1	51%	51%
Central West	-29%	3	-38%	-12%	-5%	10	-11%	10%	9%	11	-4%	25%	27%	7	16%	43%	68%	1	68%	68%
Riverina	-26%	4	-38%	-19%	-2%	11	-21%	1%	9%	12	-7%	20%	28%	5	17%	41%				
Murray	-23%	4	-36%	-16%	-6%	11	-19%	0%	9%	12	-10%	17%	26%	5	16%	37%				
ACT	-31%	2	-31%	-31%	-14%	10	-32%	35%	5%	16	-15%	25%	47%	4	35%	55%				
Goulburn Broken	-36%	5	-46%	-25%	-9%	15	-23%	-4%	7%	12	-8%	25%								
Mallee	-24%	5	-54%	-6%	-7%	13	-17%	11%	9%	12	-1%	35%	17%	2	12%	22%				
North Central	-28%	8	-50%	-1%	-10%	13	-22%	16%	13%	11	-5%	24%								
North East	-29%	5	-39%	-18%	-12%	12	-18%	-2%	7%	12	-14%	22%	27%	3	20%	34%				
South Australian MDB	-26%	8	-51%	-10%	-14%	13	-22%	5%	5%	9	-4%	19%	15%	2	13%	17%				
Wimmera	-30%	10	-53%	-4%	-14%	12	-23%	11%	13%	10	2%	22%								

1.4 Conclusions

This report has synthesised previous modelling studies into the impact of climate change on runoff and recharge for the Murray Basin NRM Cluster Region using results from the work of Post et al. (2012) and Crosbie et al. (2013). These existing modelling results were put into the representative climate futures framework to aid in effective communication.

The most frequent climate futures amongst the suite of GCMs were for warmer temperature and little change in rainfall and slightly hotter temperature and drier rainfall for both the runoff and recharge modelling. Across the Region these representative climate futures projected a decrease in both runoff and recharge as a median; however, the extreme outlier projections for both runoff and recharge can exceed ±50%.

There was considerable variation in model results both across NRM regions as well as within regions across different climate models. Overall, decreases in both runoff and recharge were projected more commonly than increases, but even the direction of change varied across climate futures, but also across climate models within climate futures and across regions. This suggests that planning within and across regions needs to be adaptive and responsive to changing conditions as the precise degree and even direction of change cannot be determined for certain.

Appendix A Spatial results for individual GCMs

The data contained in these maps is available for download on the CSIRO Data Access Portal at: http://doi.org/10.4225/08/5726ED34D9CD1

A1. Historical baseline runoff and recharge

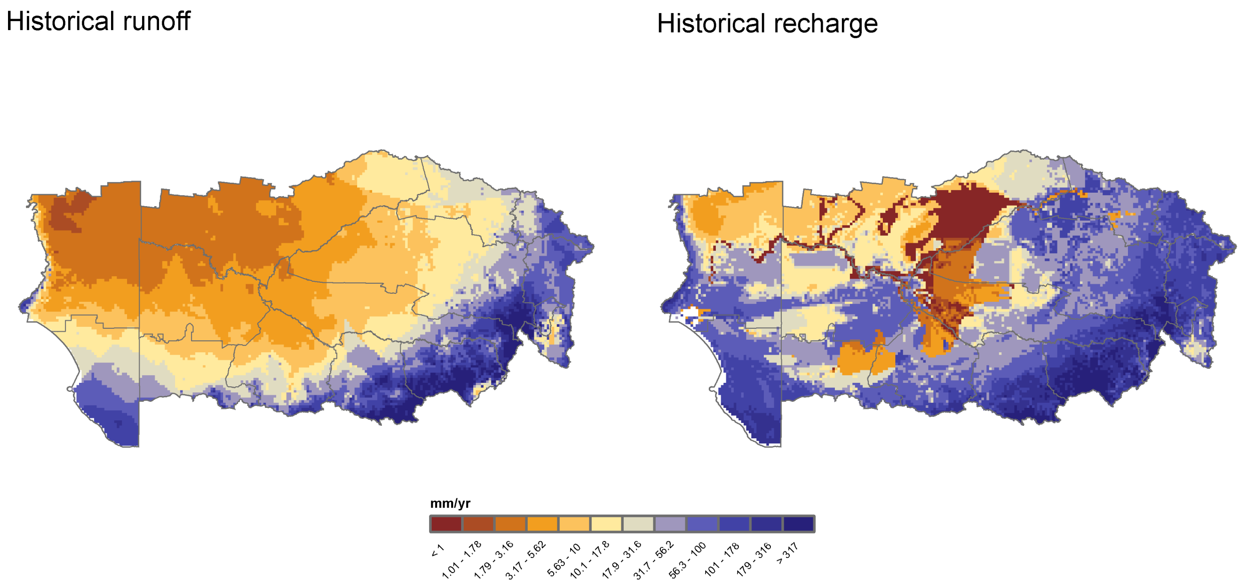

Figure A.1 Baseline historical runoff and recharge. Runoff data from Post et al. (2012), recharge data from Crosbie, et al. (2013).

A2. Change in runoff projections

Table A.1 The 15 GCMs used in the runoff modelling.

Global Climate Model	Details, modelling group, country
CCCMA_T47	Canadian Climate Centre, Canada
CCCMA_T63	Canadian Climate Centre, Canada
CNRM	Meteo-France, France
CSIRO	Mk 3.0, CSIRO, Australia
GFDL	V 2.0, Geophysical Fluid, Dynamics Lab, USA
GISS_AOM	NASA/Goddard Institute for Space Studies, USA
IAP	LASG/Institute of Atmospheric Physics, China
INMCM	Institute of Numerical Mathematics, Russia
IPSL	Institute Pierre Simon Laplace, France
MIROC	Med Res, Centre for Climate Research, Japan
MIUB	Meteorological Institute of the University of Bonn, Germany Meteorological Research Institute of KMA, Korea
MPI	Max Planck Institute for Meteorology DKRZ, Germany
MRI	Meteorological Research Institute, Japan
NCAR_CCSM	National Center for Atmospheric Research, USA
NCAR_PCM	National Center for Atmospheric Research, USA

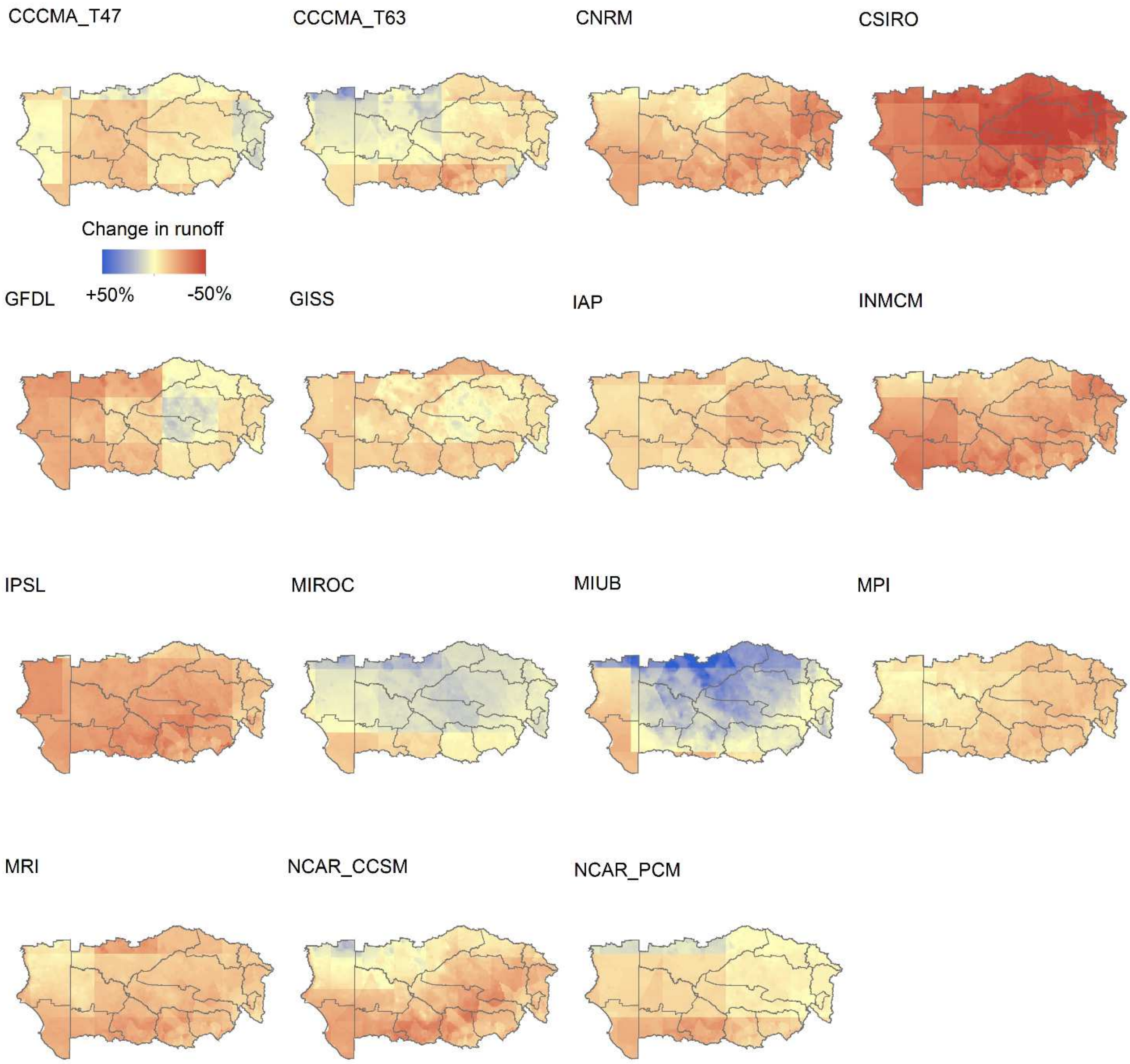

Figure A.2 Change in runoff projections for a +1°C global warming scenario for 15 GCMs. Data from Post et al. (2012).

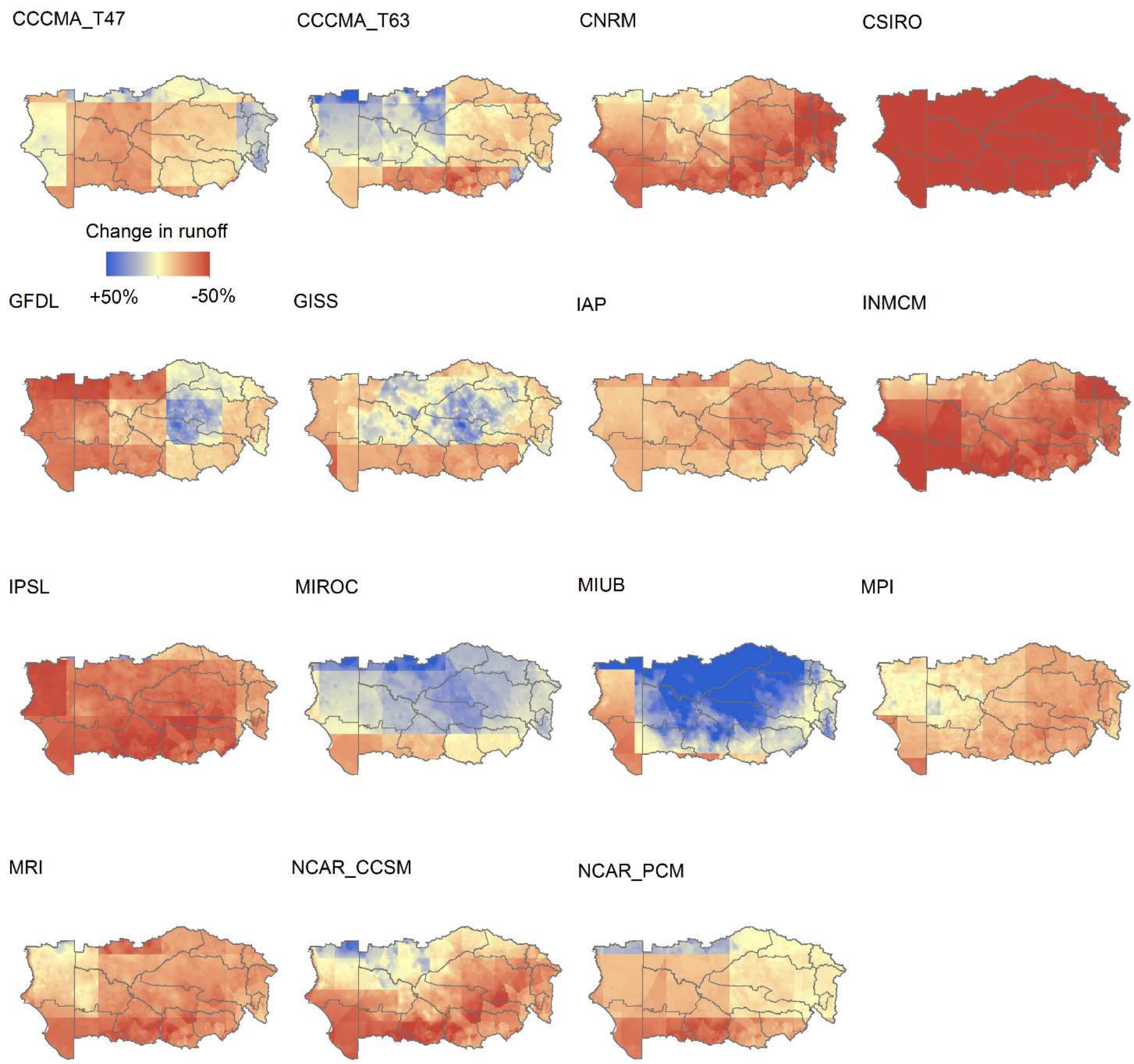

Figure A.3 Change in runoff projections for a +2°C global warming scenario for 15 GCMs. Data from Post et al. (2012).

A3. Change in recharge projections

Table A.2 The 16 GCMs used in the recharge modelling.

Global Climate Model	Details, modelling group, country
GFDL CM2.1	US Dept. of Commerce / NOAA / Geophysical Fluid Dynamics Laboratory, USA
GFDL CM2.0	US Dept. of Commerce / NOAA / Geophysical Fluid Dynamics Laboratory, USA
MIROC	Center for Climate System Research (The University of Tokyo), National Institute for Environmental Studies, and Frontier Research Center for Global Change (JAMSTEC), Japan
MIUB	Meteorological Institute of the University of Bonn, Meteorological Research Institute of KMA, and Model and Data group. , Germany / Korea
MPI	Max Planck Institute for Meteorology, Germany
MRI	Meteorological Research Institute, Japan
CCCMA	Canadian Centre for Climate Modelling & Analysis, Canada
CSIRO MK3.5	CSIRO Atmospheric Research, Australia
INGV	Instituto Nazionale di Geofisica e Vulcanologia, Italy
INMCM	Institute for Numerical Mathematics, Russia
CSIRO MK3.0	CSIRO Atmospheric Research, Australia
CNRM	Météo-France / Centre National de Recherches Météorologiques, France
IPSL	Institut Pierre Simon Laplace, France
BCCR	Bjerknes Centre for Climate Research, Norway
GISS	NASA / Goddard Institute for Space Studies, USA
NCAR	National Center for Atmospheric Research, USA

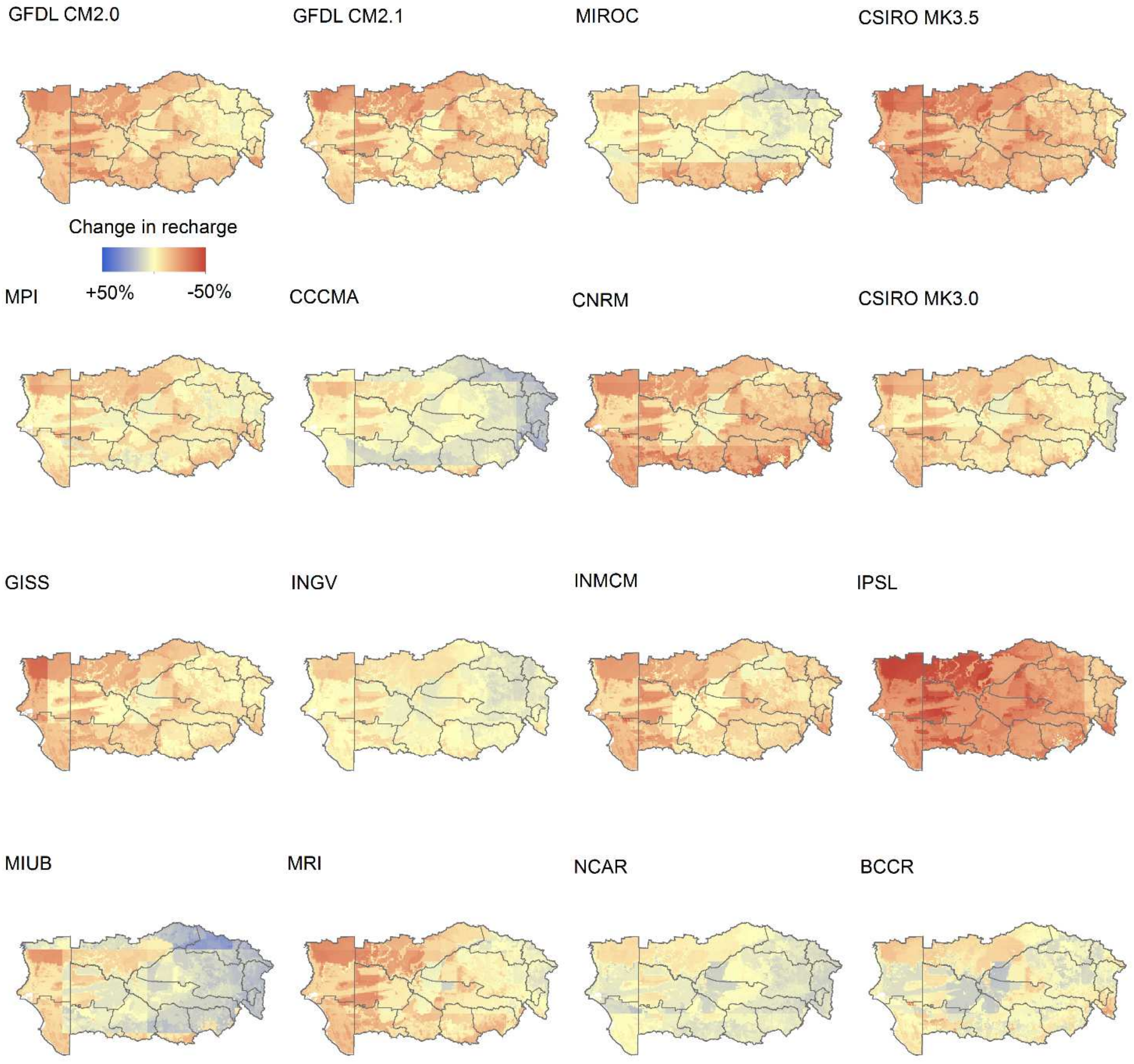

Figure A.4 Change in recharge projections for a +1°C global warming scenario for 15 GCMs. Data from Crosbie, et al. (2013).

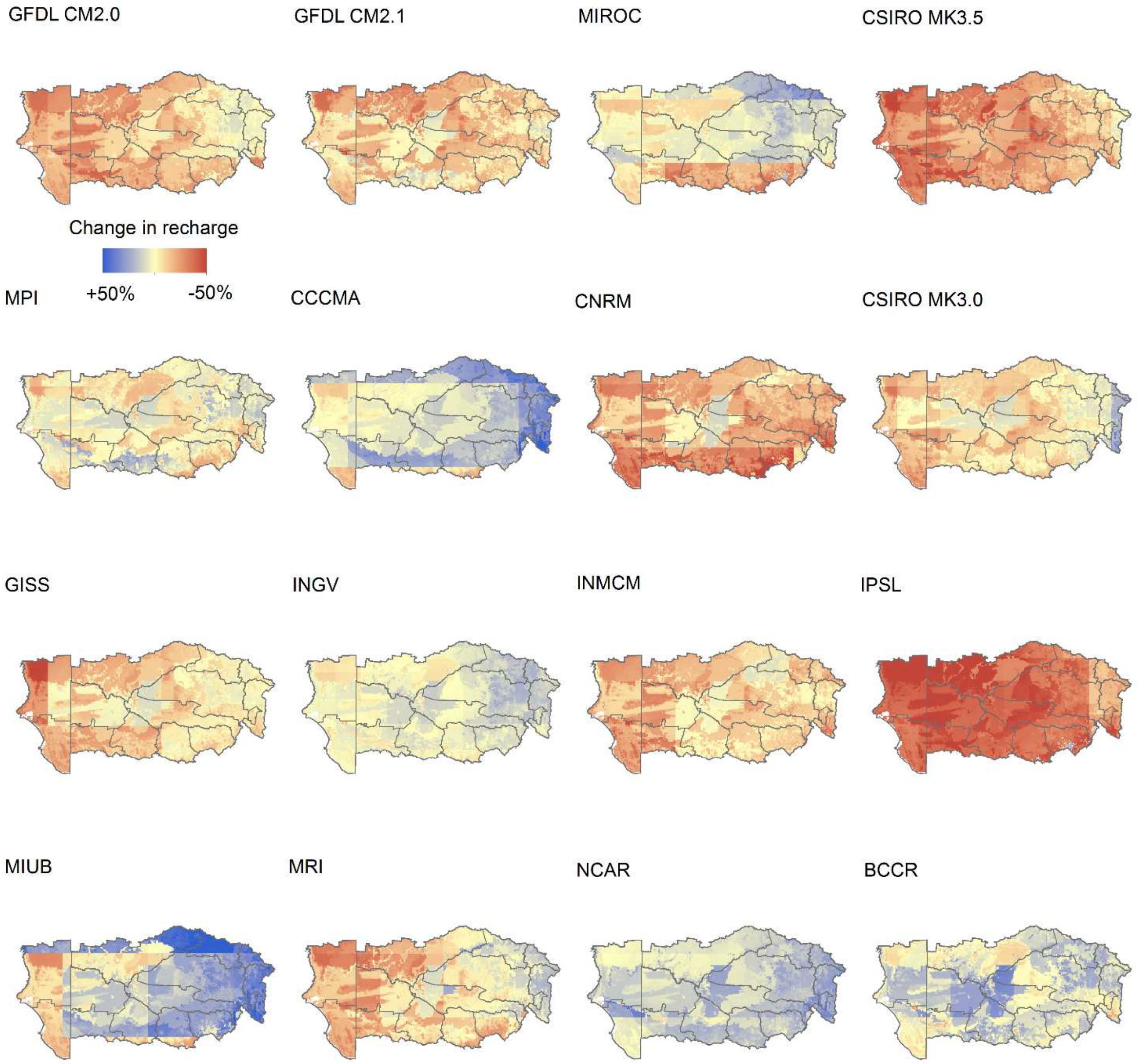

Figure A.5 Change in recharge projections for a +1.7°C global warming scenario for 15 GCMs. Data from Crosbie, et al. (2013).

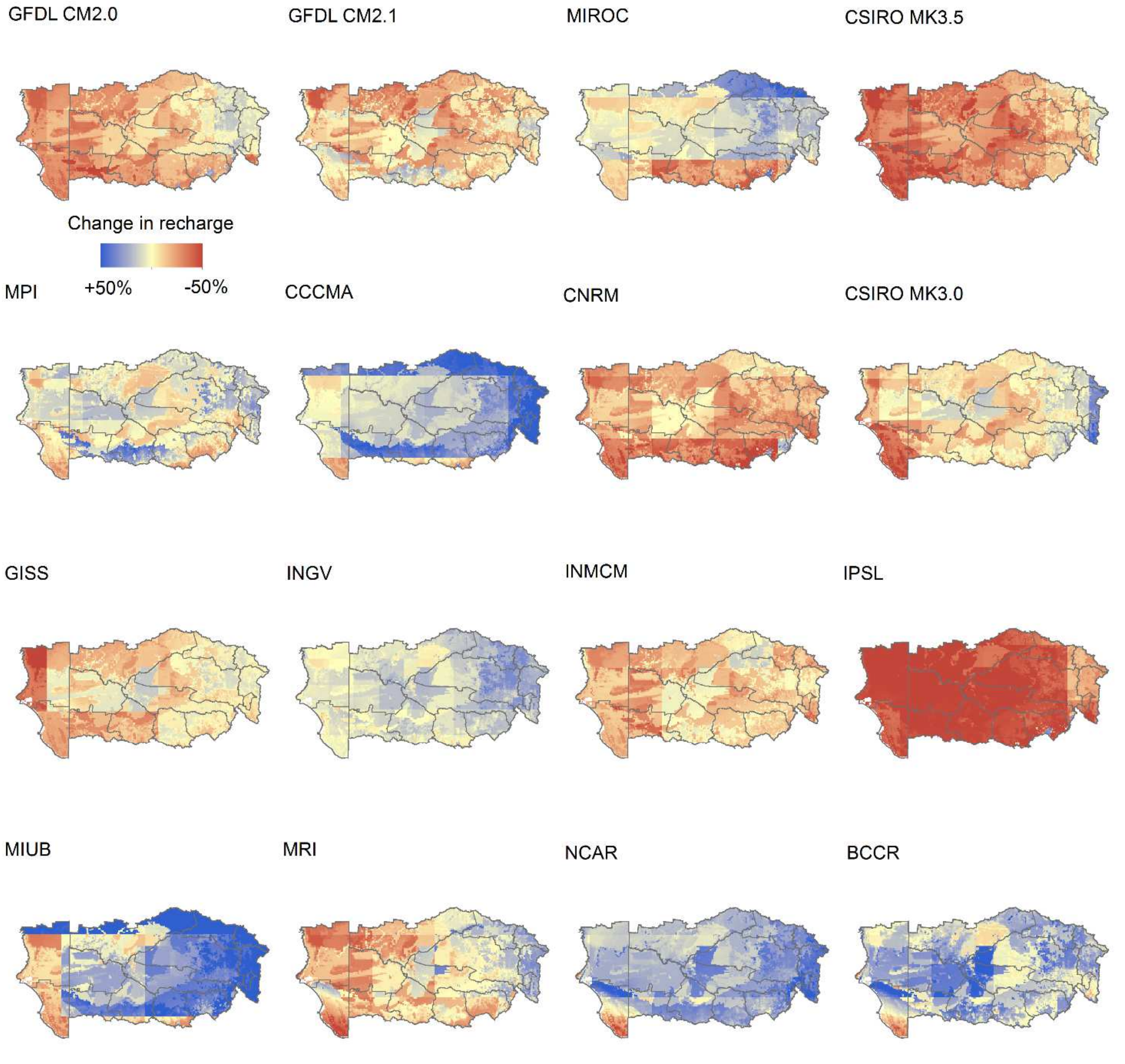

Figure A.6 Change in recharge projections for a +2.4°C global warming scenario for 15 GCMs. Data from Crosbie, et al. (2013).

References

Barron O, Crosbie RS, Charles SP, Dawes WR, Cresswell RG, Pollock D, Hodgson G, Mpelasoka FS, Ali R, Pickett T, Aryal S, Donn M, Wurcker B, Evans R and Currie D (2011) Climate change impact on groundwater resources in Australia. Waterlines report, National Water Commission, Canberra.

Chiew FHS, Peel M and Western A (2002) Application and testing of the simple rainfall-runoff model SIMHYD. In: Singh VP and Frevert DK (eds) Mathematical Models of Small Watershed Hydrology and Applications. Water Resour. Publ, Littleton, Colo, 335-367.

Chiew FHS, Teng J, Vaze J, Post DA, Perraud JM, Kirono DGC and Viney NR (2009) Estimating climate change impact on runoff across southeast Australia: Method, results, and implications of the modeling method. Water Resources Research 45.

Chiew FHS, Vaze J, Viney NR, Jordan PW, Perraud J-M, Zhang L, Young WJ, Penaarancibia J, Morden RA, Freebairn A, Austin J, P.I. H, Weisenfeld CR and Murphy R (2008) Rainfall-runoff modelling across the Murray-Darling Basin. A report to the Australian government from the CSIRO Murray-Darling Sustainable Yields Project. CSIRO, Australia.

Crosbie R, Pickett T, Mpelasoka F, Hodgson G, Charles S and Barron O (2013) An assessment of the climate change impacts on groundwater recharge at a continental scale using a probabilistic approach with an ensemble of GCMs. Climatic Change 117, 41-53. DOI: 10.1007/s10584-012-0558-6.

Crosbie RS, McCallum J, Walker GR and Chiew FHS (2008) Diffuse groundwater recharge modelling across the Murray-Darling Basin. A report to the Australian government from the CSIRO Murray-Darling Basin Sustainable Yields project. Water for a Healthy Country Flagship. CSIRO, Canberra, http://www.csiro.au/files/files/pn7z.pdf.

Crosbie RS, McCallum JL and Walker GR (2010a) Dryland diffuse groundwater recharge modelling across the Murray-Darling Basin: A report to MDBA from CSIRO/SKM GW SDL project. CSIRO: Water for a Healthy Country National Research Flagship.

Crosbie RS, McCallum JL, Walker GR and Chiew FHS (2010b) Modelling the climate change impact on groundwater recharge in the Murray-Darling Basin. Hydrogeology Journal 18(7), 1639-1656.

Crosbie RS, Pickett T, Mpelasoka FS, Hodgson GA, Charles SP and Barron O (2010c) Diffuse recharge across Australia under a 2050 climate: Modelling results. CSIRO: Water for a Healthy Country National Research Flagship, Australia.

CSIRO (2008) Water availability in the Murray-Darling Basin. A report to the Australian Government from the CSIRO Murray-Darling Basin Sustainable Yields Project. CSIRO, Australia.

CSIRO (2012) Climate and water availability in south-eastern Australia: A synthesis of findings from Phase 2 of the South Eastern Australian Climate Initiative (SEACI). CSIRO, Australia.

Meehl GA, Covey C, Taylor KE, Delworth T, Stouffer RJ, Latif M, McAvaney B and Mitchell JFB (2007) THE WCRP CMIP3 Multimodel Dataset: A New Era in Climate Change Research. Bulletin of the American Meteorological Society 88(9), 1383-1394. DOI: 10.1175/BAMS-88-9-1383.

Nakicenovic N and Swart R (2000) Special Report on Emission Scenarios. Intergovernmental Panel on Climate Change.

Post DA, Chiew FHS, Teng J, Wang B and Marvanek S (2012) Projected changes in climate and runoff for south-eastern Australia under 1 °C and 2 °C of global warming. A SEACI Phase 2 special report. CSIRO, Australia.

Ryan P, Doerr V, Doerr E, Dunlop M and Gorddard R (2016) The NRM Adaptation Planning Framework: six steps to transform NRM planning under global change. CSIRO, Australia and the Australian Resilience Centre, Beechworth.

Whetton P, Hennessy K, Clarke J, McInnes K and Kent D (2012) Use of Representative Climate Futures in impact and adaptation assessment. Climatic Change 115(3-4), 433-442. DOI: 10.1007/s10584-012-0471-z.

Zhang L and Dawes W (1998) WAVES - An integrated energy and water balance model. CSIRO Land and Water.

Contact Details

Russell Crosbie
CSIRO Land & Water
08 8303 8751
Russell.crosbie@csiro.au
www.csiro.au